Air Sampling in a Hospital
ventilated by
The Plenum System

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Colebrook (1946) has shown that the provision of clean air, especially in operating theatres and dressing rooms, is an essential condition for the prevention of wound infection. To achieve this it is necessary to have an adequate and controlled ventilation rate and the air introduced should be free from bacteria. Such conditions are being provided in modern operating theatres but in most hospitals the usual method of ventilation is by windows and is often referred to as "natural ventilation."

Most of the field studies on the bacterial content of hospital air have been done in such institutions and the present investigation was undertaken with the object of finding out the level of bacteria carrying particles in the theatres and wards of a hospital which has a controlled system of ventilation, namely the Plenum system. At the same time, because of the availability of a mobile unit designed for the sterilisation of air by recirculation over U.V. light, an attempt was made to assess the value of U.V. light used in this way as a means of reducing the bacterial content of the air in the hospital wards. The effect of U.V. light in one operating theatre was also investigated.

Methods Used.

The slit sampler used (Bourdillon, Lidwell and Thomas, 1941), draws air on to the surface of a rotating agar plate at the rate of 1 cubic foot per minute. Samples of air were taken in the following places: the main air duct and a small subsidiary duct, certain large and small wards and some operating theatres.

The culture medium used was 5 per cent horse blood agar. Plates, after exposure, were incubated aerobically at 37°C. for twenty-four hours, when colony counts were made.

They were incubated for a further twenty-four hours and re-examined with the object of recording colony types resembling pathogenic and non-pathogenic bacteria. During the period of sampling, plates were run usually at intervals of two and a half minutes and the rate of rotation of the plate was usually thirty seconds: in some experiments a two-minute rotation was used. Frequent notes were made of the conditions prevailing and of any changes occurring during the period investigated and a frequency curve was drawn for each session of sampling.

Results.

Main Air Duct and Subsidiary Ducts.

Tests were carried out in April and May, 1956, under "winter" conditions: one intake fan was running in the ventilation shaft and the ventilation changes in the wards were seven and a half per hour. Under "summer" conditions two intake fans were running and the ventilation changes in the wards were eleven to twelve per hour. Under "winter" conditions the air current in the duct was like a gale blowing at the east end, strongly felt in the middle and still perceptible at the west end. Samples were taken at the east end, half-way down the duct and at the west end, and also from an air duct leading directly upward to an inlet in ward 20.

The colonies which were seen resembled those of common aerial contaminants with a few moulds. They were few, the numbers varying from nil on two occasions to fifteen on one occasion. The total amount of air sampled was 76 cubic feet, and the average number of bacteria per cubic foot of air, taking all samples together, was 2.27.

The lowest counts were found in the small air duct leading directly to ward 20 at the furthest end of the duct from the intake fan.

Wards.

The large wards are uniform in size, being 94 ft. long by 24 ft. wide by 14 ft. high, with a cubic capacity of 31,584 cubic feet. Each has nine air inlets and twenty grilles for air exit, and each contains twenty-two beds. Four different wards were investigated, two medical and two surgical. The slit sampler was placed on a trolley beside a bed half-way down the ward, 3 ft. 4 ins. above floor level and about 5 ft. from the wall. Each plate was exposed for a half minute.

Conditions in a small ward and a clinical room were also investigated. Each has one air inlet situated near the ceiling and one outlet grille at floor level. The ventilation rates were seven and a half changes per hour in winter and twelve changes per hour in summer.

The small ward was a two-bedded male surgical ward, 16 ft. long by 12 ft. wide and 11 ft. 7 ins. high, with a cubic capacity of 2,224 cubic feet. It has one door which opens on to the short corridor leading from the large male ward to the main hospital corridor. The clinical room was situated off the short corridor leading from a large gynæcology ward to the main corridor. Its size is 17 ft. 3 ins. long by 8 ft. 4 ins. wide by 8 ft. 6 ins. high, and its cubic capacity is 1,221 cubic feet. It is used for the examination of out-patients and for side-room tests. The floors of the wards were not highly polished but slightly sticky, and blankets were not treated with oil or any other special substance.

All air sampling was done under "winter conditions" and the slit sampler was placed at the same height as in the large wards, between the beds in the small ward and about the middle of the clinical room.

The results of tests done with the normal ward routine in progress under "winter" and "summer conditions" are summarised in table 1.

Frequency curves were made from the results found in each sampling session and the examples shown in fig. 1 illustrate the values found under these different working conditions. From both tables and figures one can see that high bacterial counts are associated with increased activity in the wards and that there is a

TABLE 1.

Wards.

	Ward	Date and Time	Total Amount Air Sampled Cu. Ft.	Average Number of Colonies per Cu. Ft. of Air	General Conditions
Winter Conditions	2 Male Medical	14/2/56 11.30	9.50	86.52	Bed-making, curtains, floor polishing.
	2 Male Medical	2/3/56 14.30	12.0	104.66	Bed-making for 30 minutes; ward quiet, then visitors.
	8 Male Medical	15/2/56 11.30	9.00	94.55	Sweeping floor, dressing wound, lumbar puncture being done.
	12 Male Surgical	27/2/56 11.30	27.25	109.35	Bed-making, curtains, much activity.
	12 Male Surgical	2/2/56 11.30	7.5	49.05	Floor polishing, curtains, moderate activity.
	12 Male Surgical	7/2/56 11.20	26.0	118.69	Bed-making, curtains, floor polishing.
	18 Female Surgical	22/2/56 11.50	8.0	27.0	No curtains, very quiet.
	12 Side Ward	2/12/56 12.00	20.0	57.7	Generally quiet, trolley with patient also in ward.
	12 Side Ward	16/12/56 12.15	24.0	106.14	Bed-making.
	Clinical Room	24/2/56 14.45	5.5	56.9	Moderate activity, curtains.
Summer Conditions	2 Male Medical	9/8/56 11.50	12.0	95.08	Curtains being taken down, mattress removed.
	12 Male Surgical	10/8/56 11.45	11.5	65.04	Bed-making, curtains, moderate activity.

Results of air sampling in large and small wards under winter and summer conditions, without re-circulation of air over U.V. light.

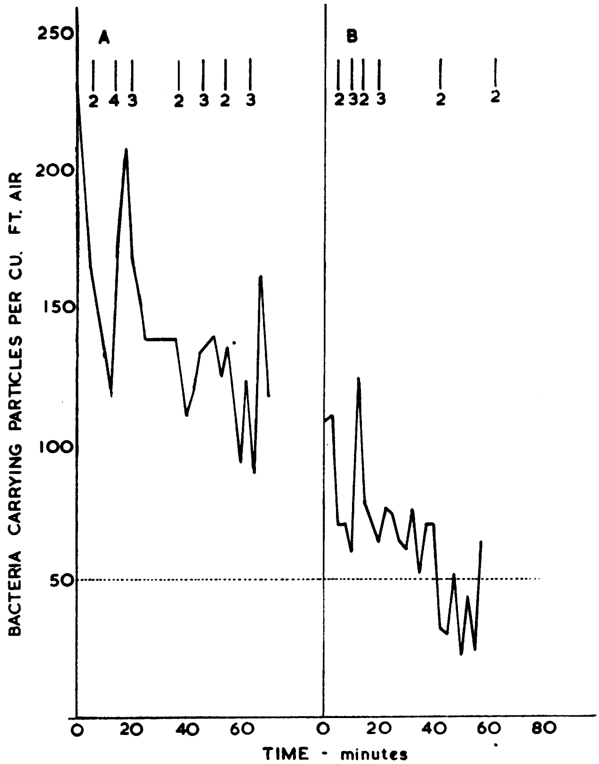

Fig. 1—Illustrates the findings during air sampling in a male surgical ward under winter conditions (curve A), and summer conditions (curve B).

marked variation in the average numbers of bacteria found in different sampling sessions, the lowest in any session being 27 and the highest 118.

It is difficult to classify degrees of activity, but for comparison the following grades may be used :—

1. *Quiet* - This denotes the minimum amount of movement either by patients or staff.

2. *Moderate* would include the usual ward activity of persons going to and fro, carrying out minor treatment without excessive amount of movement of patients, staff, objects or clothes.

3. *Marked Increase* connotes much rapid movement of patients or staff with passage of trolleys and stretchers, moving of curtains, sweeping and dusting.

4. *Maximum* Bed-making, and when this is associated with the morning and evening work in the wards activity is at its maximum.

In the frequency curves (shown in figs. 1 to 7), these degrees of activity are denoted by the numerals 1 to 4 so that one may co-relate activity and the bacterial counts.

Operating Theatres.

Three theatres ventilated by the same Plenum system were investigated under "summer" and "winter conditions" as well as during operating sessions and periods when the theatre was not being used or being cleaned. For purposes of comparison a sampling session was done in a fourth theatre, situated in another hospital with its own system of controlled positive pressure ventilation.

During sampling, plates were run at intervals of two and a half minutes, the rotation period of each being a half minute. The sampler was placed on a trolley 3 ft. 4 ins. above the floor and at a distance of about 6 ft. from the head of the patient.

Most sampling was done in *theatre A*. Its dimensions are 25 ft. long by 16 ft. 3 ins. wide by 11 ft. 7 ins. high, and its cubic capacity 4,500 cubic feet. The ventilation rate was 2.9 changes per hour in winter, and in summer eleven to twelve changes per hour. It was fitted with two U.V. lamps suspended from the ceiling at a height of 7 ft. 3 ins. from the floor. The lamps were usually screened from below. The screens can be removed and the lamps used as a source of direct U.V. light. Circulation of air was assisted by two fans situated on a shelf 9 ft. above the floor.

The theatre is situated between two of the short corridors which connect the large wards to the main hospital corridor and it communicates with each by double doors. During operations it is usually necessary to have these doors open because of the discomfort felt by the staff if they are kept shut. Screening curtains are drawn across the doorways and there is no effective barrier to the entry of contaminated air from the corridors. Sterilisation of instruments is done in this theatre—there is no anæsthetic room and surgeons have to scrub up and prepare for operations in the theatre. It is used for general and emergency surgery. There is a good deal of equipment in it.

Theatre B is a little smaller than theatre A. Its dimensions are 24 ft. 4 ins. long by 20 ft. 8 ins. wide by 9 ft. 6 ins. high, with a cubic capacity of 4,100 cubic feet. It opens off the short corridor from ward 20 and has only one pair of swing doors.

Sterilisers are in a separate room and there is a small alcove for surgeons to scrub up in, opening off the theatre. The ventilation rate is seven changes per hour in winter and eleven to twelve in summer. This theatre is also used for general and emergency surgery.

Theatre C had a cubic capacity of 5,300 cubic feet. Its size is 32 ft. 3 ins. long by 24 ft. 6 ins. wide by 11 ft. 6 ins. high. It is situated on the north side of the main corridor away from the wards and has separate sterilising and scrubbing-up rooms. It communicates with the main hospital corridor through the anæsthetic room. Its main use is for gynæcological surgery and major dental operations. The ventilation rate was 4.4 changes per hour in winter and eleven in summer.

Theatre D.—This is part of a recently reorganised theatre suite in an adjacent hospital. It has a system of controlled positive pressure ventilation in which the air is driven into the theatre at ceiling level. Its size is 45 ft. 4 ins. by 36 ft. 6 ins. by 12 ft. high. The cubic capacity is 19,861 cubic feet, and the ventilation changes eleven per hour. Sterilisers and all other equipment are outside the theatre.

TABLE 2.

OPERATING THEATRES.

	Theatre	Date and Time	Total Amount Air Sampled Cu. Ft.	Average Number of Colonies per Cu. Ft. of Air	General Conditions
Winter Conditions	A	23/1/56 14.45	6.00	112.33	Cleaning in progress, blanket shaken.
	A	18/4/57 15.10	12.00	53.41	Operations in progress, much activity.
	A	26/4/57 11.45	12.00	46.41	Operations in progress, much activity.
	B	19/3/56 11.30	8.50	66.35	Operations in progress, much activity, *staph. pyogenes* isolated.
	B	24/3/56 11.30	9.00	18.23	Quiet, cleaning in progress.
	C	23/2/56 14.50	10.00	17.2	Dental operations in progress, quiet.
Summer Conditions	A	30/7/56 11.53	12.50	28.32	Operations in progress, much activity.
	A	1/8/56 12.20	6.00	21.0	Quiet, cleaning in progress.
	A	3/8/56 12.20	12.00	31.58	Operations in progress, quiet.
	A	4/8/56 11.50	6.00	69.5	Preparation for operation, much activity, drainage of empyema before sampling began.
	B	16/8/56 14.30	12.00	31.16	Operations in progress, moderate activity.
	D	13/4/56 12.30	10.00	5.6	Operations in progress, quiet; theatre has independent positive pressure ventilation.

Results of air sampling of operating theatres under winter and summer conditions without the use of U.V. light.

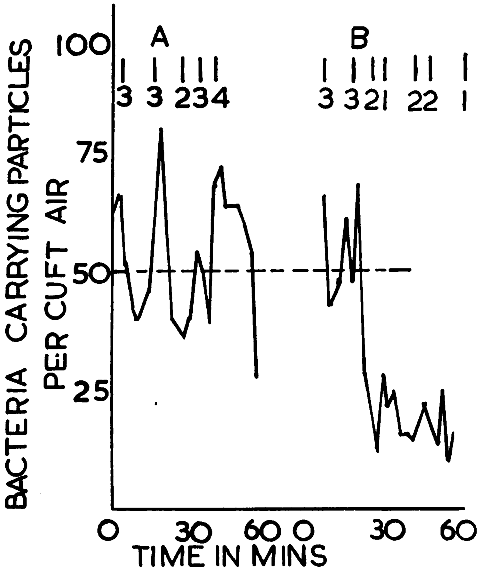

Fig. 2.— Illustrates the findings during air sampling in operating theatre A under winter conditions (curve A), and summer conditions (curve B).

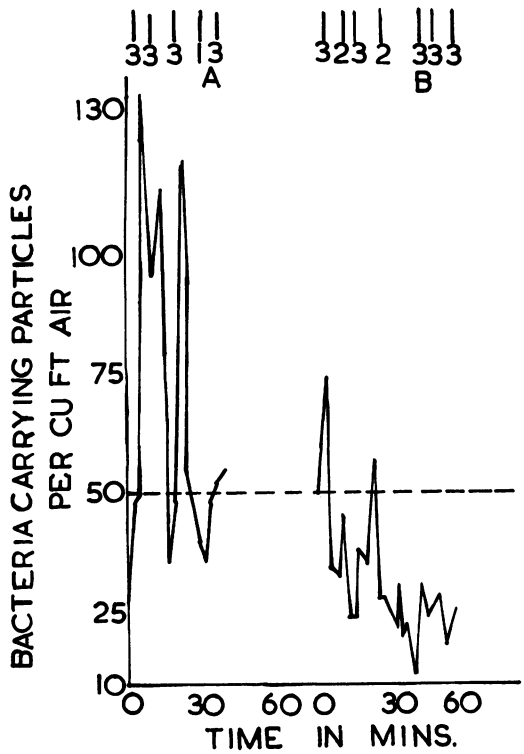

Fig. 3.—Illustrates the findings during air sampling in operating theatre B under winter conditions (curve A), and summer conditions (curve B).

The results of sampling in theatres A, B and C under winter conditions and of theatres A, B and D under summer conditions are summarised in table 2. Notes on the conditions prevailing during the period of investigation are included in the tables.

Frequency curves were also made from the results obtained in each sampling session and curves selected from them to illustrate the findings in "winter" and in "summer conditions" are shown in figs. 2, 3 and 4. Degrees of activity are indicated by the numerals 1 to 4.

Six sampling sessions were carried out under "winter conditions." The three sessions in theatre A and one of the two in theatre B produced high average counts and in each case the degree of activity prevailing during the sessions was high. The values of 18.33 in theatre B and 17.20 in theatre C were obtained when conditions were quiet, in B during cleaning, and in C during a very quiet operating session.

Six sessions were carried out during "summer conditions." Of these, four were in theatre A, one in theatre B and one in theatre D. During three of the sessions in theatre A the values found show a definite drop as compared with those found under "winter conditions." The fourth produced the high count of 69.50. This was found during a session of thirty minutes sampling, which was preceded by an operation for drainage of an empyema. The lowest count (5.60) obtained during any session was in theatre D where the conditions were better than those in any of the other theatres sampled.

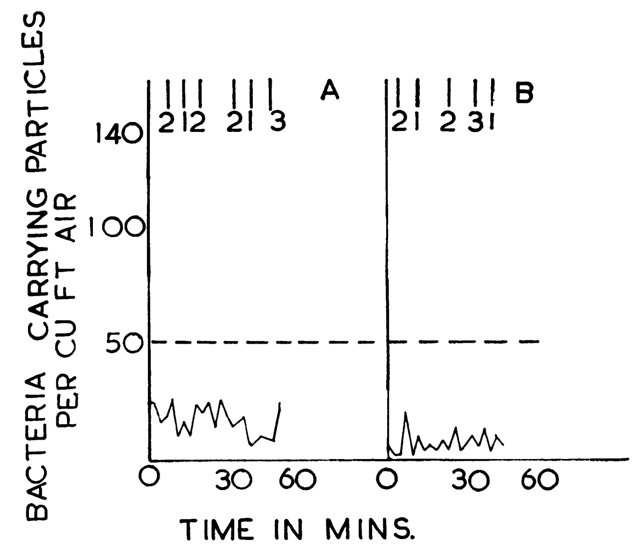

Fig. 4.— Illustrates the findings during air sampling in operating theatre C (curve A) during winter conditions, and in theatre D (curve B), which has a special system of controlled ventilation.

During the course of these investigations in operating theatres the total number of plates examined was 325. Counts of 10 per cubic foot air and under, were found on 38 of them, and 17 of these were obtained from the air of theatre D during one period of sampling.

Wards. *Ultra-Violet Light.*

The lethal effect of the recirculation of air over U.V. light upon suspended bacteria was investigated and for this a special mobile unit was available.

The prototype model used was designed by Hanovia Ltd. of Slough in association with Messrs. R. B. Stirling of Glasgow, who were responsible for its manufacture and to whom we are indebted for the loan of first one model and later a second. It consisted of a rectangular metal box 42″ high by 13″ wide by 13″ deep. An air intake fan is situated close to the bottom of one of the panels and it draws air in through three filters made of viscous coated glass fibre situated in the sides of the machine close to the top. The filtered air drawn in passes over two fifteen-watt low pressure M.V. discharge lamps in quartz, fitted with ozone eliminating liquid filter jackets and it is discharged by the fan at the lower end of the model. The air flow over the U.V. tubes can be regulated by means of a switch to rates varying from 200 to 264 cubic feet per minute.

The idea behind the design of this mobile unit for air disinfection was that by placing it between beds in surgical wards the numbers of organisms in the air would be so reduced that the possibility of pathogenic bacteria passing from one

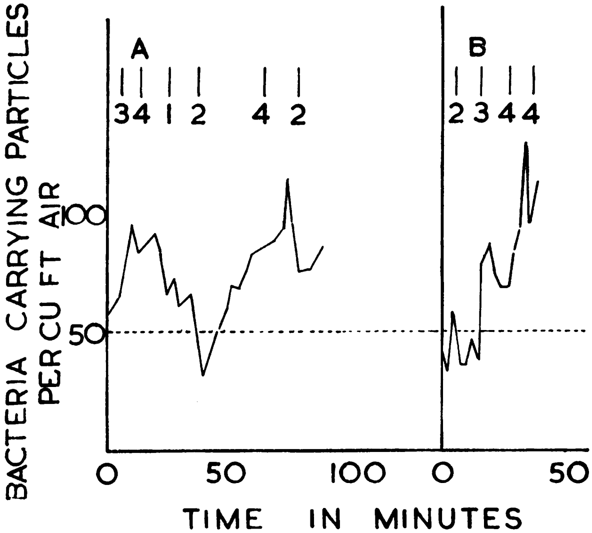

Fig. 5.—Illustrates the findings during air sampling in a male surgical ward when the air in the neighbourhood of the slit sampler was being re-circulated over U.V. light. Curve A shows the results when the rate of re-circulation was 222 cubic feet per minute, and curve B when it was 444 cubic feet per minute.

bed to another would be very slight. Its designers thought that its use would be specially advantageous during surgical dressings.

The mobile unit was used in the wards and small clinical room, and was tested only under "winter conditions." In the wards it was placed beside the slit sampler and a patient's bed.

Results are summarised in table 3. In fig. 5 the two frequency curves shown illustrate the findings obtained during periods of sampling in a male surgical ward when either one or both mobile U.V. units were being used.

In fig. 6 the frequency curves illustrate the results obtained in the small clinical room with and without the use of the U.V. mobile unit.

As in the results obtained from sampling without U.V. light there is a marked variation in the average number of bacteria per cubic foot of air in different sessions, the lowest average being 12.14 and the highest 185.75. High counts were found when blankets were shaken or activity marked. Counts in the wards obtained during comparable conditions of activity do not differ appreciably from those found under normal conditions. Counts in the clinical room were lowered by the use of one mobile unit to an average of 31.55 bacteria carrying particles per cubic foot of air and to an average of 12.14 by the use of two units, which were circulating air each at the rate of 222 cubic feet per minute for a period of two and a half hours before testing and while samples were being taken.

Operating Theatres.

The lethal effects of direct and indirect U.V. light was assessed in theatre A during both "winter" and "summer conditions." Results of using indirect U.V. light are summarised in table 4 and shown in the frequency curves exemplified in fig. 7.

TABLE 3.

WARDS.

WINTER CONDITIONS

WARD	DATE AND TIME	TOTAL AMOUNT AIR SAMPLED CU. FT.	AVERAGE NUMBER OF COLONIES PER CU. FT. OF AIR	GENERAL CONDITIONS
12 Male Surgical	17/5/56 16.30	8.5	68.35	Bed-making, curtains, moderate activity, two U.V. machines in use.
12 Male Surgical	26/1/56 11.40	10.0	126.4	Bed-making, curtains, floor polishing, much activity, one U.V. machine in use.
12 Male Surgical	2/2/56 11.30	4.5	44.4	Dressing being done, curtains, moderate activity, one U.V. machine in use.
12 Male Surgical	8/2/56 11.25	26.0	41.76	Patient vomiting, another getting out of bed, dressing being done, curtains, moderate activity, one U.V. machine in use.
12 Side Ward	10/1/56 14.30	10.0	33.7	Quiet, visitors in, one U.V. machine in use.
12 Side Ward	12/1/56 12.15	8.0	185.75	Activity in corridor outside open door, blankets and clothes shaken, one U.V. machine in use.
Clinical Room	24/2/56 15.10	4.5	31.55	Quiet, then cloak shaken, one U.V. machine in use.
Clinical Room	18/5/56 15.15	7.0	12.14	Two U.V. machines in use for two hours before test began, moderate activity.

Results of air sampling in large and small wards under winter conditions with the re-circulation of air over U.V. light.

Under "winter conditions," both when blankets were shaken and under conditions of moderate activity, the levels found were lower when the U.V. lamps were being used than when they were not, but, as is shown in the discussion which follows, they did not reach satisfactory limits in any test. Under "summer conditions," the average values obtained in two sampling sessions were 23.66 and 23.41 bacteria carrying particles per cubic foot of air respectively—the lowest result found in this theatre, but in three other sessions during very hot and humid conditions, the bacterial counts were about the same as those found in winter without U.V. light.

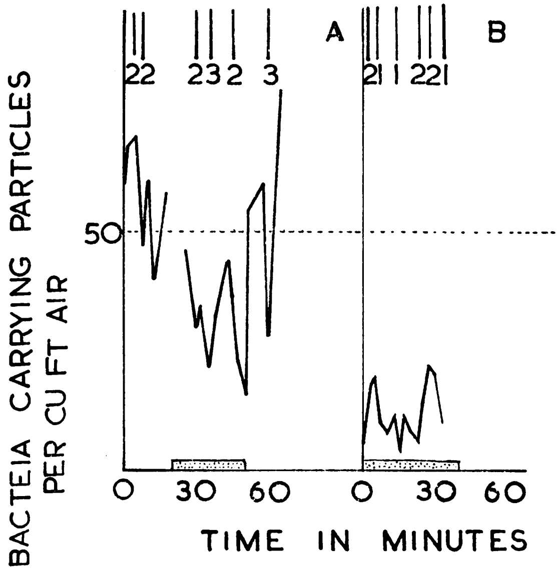

Fig. 6—Illustrates the findings during air sampling in the small clinical room (curve A) when one machine was in use (re-circulation of air 222 cubic feet per minute) and (curve B) when two machines were in use (re-circulation of air 444 cubic feet per minute). The hatched areas indicate the periods when the U.V. machines were running.

The effect of direct U.V. light in a closed theatre was investigated. After a period of fifty-three minutes exposure the bacterial count of the air was reduced to an average of two bacteria carrying particles per cubic foot, which is slightly less than the average value found from the air which comes into the theatre from the ventilating shaft (2.27).

The rise to this mean level was the result of the entry of two persons and the slit sampler. After ten minutes a blanket was shaken and the number of bacteria carrying particles rose immediately to 156 per cubic foot of air. The record shows that quiet conditions continued and the numbers fell to 50, ten minutes after the blanket was shaken, to 24 at twenty minutes, to 20 at twenty-five minutes, and to 6 at twenty-eight minutes after.

From this experiment one might assume that provided conditions in the theatre were quiet, exposure to direct U.V. light for half an hour, combined with the low ventilation rate of 2.9 c.p.h. would be enough to bring the level of bacteria carrying particles to levels safe for surgery, provided that movement was reduced to a minimum and the measures suggested later were put into effect.

TABLE 4.

OPERATING THEATRE A.

	Date and Time	Total Amount Air Sampled Cu. Ft.	Average Number of Colonies per Cu. Ft. of Air	General Conditions
Winter Conditions	12/3/56 14.30	6.0	66.3	Theatre closed and exposed to direct U.V. light for one hour before sampling began. During sampling a blanket was shaken.
	18/1/56 12 noon	6.0	70.83	Quiet, except that a blanket was shaken during sampling.
	30/4/57 15.30	12.0	37.58	Operations in progress, moderate activity.
Summer Conditions	31/7/56 12 noon	12.0	23.66	Operations in progress, moderate activity.
	2/8/56 11.40	12.0	23.41	Operations in progress, moderate activity.
	13/6/57 15.30	6.0	38.83	Operations in progress, moderate activity, very hot and humid.
	18/6/57 15.40	4.5	58.22	Operations in progress, much activity, very hot and humid.
	25/6/57 12.15	5.0	63.2	Operations in progress, moderate activity, very hot and humid.

Results of air sampling in operating theatre A while indirect U.V. light was being used, under winter and summer conditions.

DISCUSSION.

For the purpose of this investigation it has been assumed that the standards proposed by Bourdillon, Lidwell and Thomas (1948) for the bacterial content of the air of occupied rooms, operating theatres and rooms used for surgical dressings are reasonable, especially as no other values or standards have yet been suggested. Bourdillon and Colebrook (1946), as the result of extensive work in operating theatres and dressing rooms, stated that in their opinion the number of bacteria carrying particles in the air should not exceed 20 per cubic foot, where minor operations and dressings are done; for major operations the level should not exceed 10, and for brain surgery or operations on patients with a very low tissue resistance the numbers should be not more than 2-0.1. These standards were confirmed by Bourdillon *et al.* (1948) as the result of many observations in operating theatres. In addition, following upon extensive field trials, they suggest that it is not unreasonable to take fifty bacteria carrying particles per cubic foot of

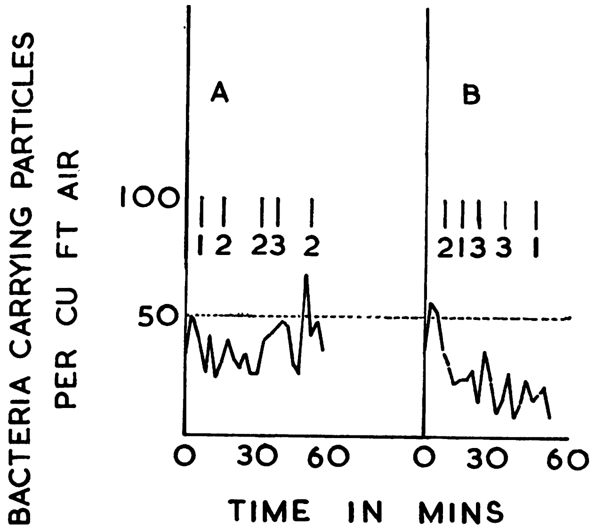

Fig. 7.—Illustrates the findings during air sampling in theatre A while it was under the influence of indirect U.V. light. Curve A was obtained under winter conditions, and curve B under summer conditions.

air as an upper limit to be considered satisfactory in any ordinary occupied space. Bourdillon and Colebrook (1946) have also shown that the estimation of the level of the general bacterial flora of the air is of value in surgical dressing rooms and operating theatres. In fact by its use they showed that a bacteria-free atmosphere was an essential factor in the prevention of the septic infection of burns.

Reid, Lidwell and Williams (1956) have discussed the question of using total bacterial counts as an index of air hygiene. Their results show that counts of the general bacterial flora of the air in schools do not bear any relationship to the incidence of cross infection in respiratory diseases, but that there is a significant relationship between the numbers of *streptococcus salivarius* in the air and the risk of classroom transfer of measles. On this account and because most of the bacteria isolated are non-pathogenic cocci, they state that estimations of the general bacterial flora of the air are not likely to be a reliable indication of the general state of air hygiene, at least so far as respiratory diseases are concerned. On the other hand, it has been shown by Wright, Cruickshank and Gunn (1944) that during an outbreak of streptococcal infections of the middle ear and mastoid cells complicating measles, the mean bacterial count in the air of a ward treated by

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oiling clothes and bedclothes fell by 92 per cent., and at the same time the count of hæmolytic streptococci fell by 99 per cent., as compared with the results obtained in the control ward in which no special preventive measures were taken. In addition, the rate of complications in the test ward fell to 18.6 per cent., as compared with a rate of 73.3 per cent. in the control ward. This would seem to indicate some correspondence between the mean bacterial count per cubic foot of the air in the measles ward and the incidence of complications due to hæmolytic streptococci.

Whether the general bacterial count of the air in the wards or theatres bears a relationship to the incidence of wound infection has yet to be shown. It is probable that more information could be obtained by a search for the occurrence or incidence of pathogens such as *staphylococcus pyogenes* as has been suggested by Shooter, Griffiths, Cook and Williams (1957), or potential pathogens such as *pseudomonas aeruginosa* or *escherichia coli,* since these organisms are from time to time associated with outbreaks of wound infection in hospital wards.

In the present study the findings show that in both wards and theatres the numbers of bacteria carrying particles per cubic foot of air are high.

Wards.

In the wards the tables and frequency curves show that high counts are associated with increased activity and counts below fifty are found only in quiet periods, which is a finding similar to that reported by Bourdillon *et al.* (1948). Since the wards are seldom quiet during the day, it follows that the number of bacteria in the air is maintained at a level of over fifty for long periods, a level which would be considered unsatisfactory in an ordinary occupied space according to the standards of Bourdillon *et al.* (1948).

The mean values compare, as a whole, not unfavourably with those given by Bourdillon *et al.* (1948) for hospital wards in London during the winter of 1943-44, when the highest mean value obtained was 667 and the lowest 92; though these high figures may be accounted for by the difficulties of ventilating overcrowded wards during the black-out. Colebrook and Cawston (1948) emphasised the importance of adequate ventilation. In a ward ventilated by several open windows on each side, they obtained mean values as low as 6 to 13 bacteria carrying particles per cubic foot of air when the ward was quiet, even though dressings were in progress. During bed-making, with the windows open, the mean count was 77. With nearly all the windows closed one count found during a dressing in the same ward reached the high level of 619.

Since ventilation rates were constant in the present series of experiments and the number of bacteria in the incoming air had the low average value of 2.27 per cubic foot, the effect of various kinds of activity of the bacterial count could be assessed.

As a result of making observations at intervals of two and a half minutes or oftener, and co-relating these observations with the bacterial counts, the ability of the slit sampler to detect frequent and sudden changes in the bacterial content of the air was confirmed.

When frequency curves are examined in conjunction with the notes kept during sampling it is evident that any movement, even very slight, of fabrics, curtains, clothing and bed-clothes, scatters a shower of organisms into the air. The greater the movement or disturbance of clothing the higher are the counts, and bed-making or the shaking of blankets produces the highest counts of all. A count of 516 was once obtained during bed-making, and the shaking of a blanket in a small ward produced a count of 799 bacteria carrying particles per cubic foot of air.

These results confirm those found by many workers; namely, that clothing, bedclothes and blankets are heavily loaded with bacteria and that the bacteria are cast into the air by any movement of the fabrics. Indeed it has been shown repeatedly that blankets are one of the chief sources of bacteria in a ward, if not the main reservoir. Thomas and van den Ende (1941) discussed the question of blankets as a bacterial reservoir as long ago as 1941 and estimated that a single blanket might harbour up to one million organisms. Bourdillon and Colebrook (1946) showed that blankets taken directly from wards and shaken in a sterile dressing room liberated up to 471 bacteria per cubic foot of air. Frisby (1957), by homogenising a square inch of blanket in a measured amount of broth and making our plate cultures, estimated that a whole blanket could harbour from forty to eighty million bacteria.

It has been shown by Bourdillon and Colebrook (1946) and Barnard (1952) that the ordinary process of laundering blankets does not render them free from bacteria, and Barnard found that most freshly-laundered blankets contained *staphylococcus aureus*.

Efforts to deal with the difficult problem of ridding blankets of bacteria have been made from time to time since 1941 (van den Ende, Edward and Lush, 1941; Thomas and van den Ende, 1941, and van den Ende and Thomas, 1941). Briefly stated these methods included the treatment after washing, by oil emulsions or liquid paraffin, and the use of detergents such as fixanol (Rountree, 1946), and cetyl trimethylaminobromide (Blowers and Wallace, 1955) in the laundering process. The latter method, known as the "lissapol-cirrasol" technique, has been used in an extensive investigation on the cleaning of blankets by Frisby (1957). He states that "provided that blankets are washed frequently—for example after every patient—this technique is adequate to keep ordinary woollen blankets clean."

It has been suggested that blankets might be made of cotton or terylene fabrics instead of wool, because such materials may be boiled without being damaged. Blowers has boiled a set of terylene blankets fifty times without causing them an appreciable amount of damage, and Frisby states that terylene blankets used in his investigation were boiled fourteen times without being damaged. Osborne, Littlewood and Atkinson (1957) sterilised terylene blankets by autoclaving after washing, and found that they remained soft, white and fluffy after six such treatments. Terylene blankets are light and warm and would seem to be ideal for hospital use, but they have the disadvantages of being expensive and liable to build up a high static electrical charge which would preclude their use in operating theatres.

Frisby's observations about the need for the frequent washing of woollen blankets apply equally forcibly to those made of terylene, for though a blanket may be clean and sterile when placed on a patient's bed, it soon acquires a fresh load of bacteria, and if the patient has a septic, discharging wound there will be large numbers of pathogens in the bedclothes and blankets. If the numbers of pathogens in the hospital environment are to be kept within reasonable limits, then the blankets, as well as the other bedclothes should be efficiently washed upon the discharge of every patient from hospital.

Some attention should also be given to the clothing of the persons who work in the wards. Duguid and Wallace (1948) have shown that large numbers of bacteria carrying particles were liberated from clothing, even during a period of very slight activity, and that 10 per cent. of these remained airborne for half an hour. They also showed that nasal carriers of *staphylococcus aureus* infected the air to a greater degree by liberation of dust from clothing than by sneezing, and that *staphylococcus aureus* was present in about 0.1 per cent. of the bacteria carrying particles which were shed into the air from the clothing of carriers.

The results of the present investigation show that the level of twenty bacteria carrying particles recommended by Bourdillon and Colebrook (1948) as the highest mean value to be permitted in the air of a room used for surgical dressings, is very far from being attained in the wards of this hospital where it is the usual practice to do surgical dressings as well as minor surgical procedures, such as lumbar punctures. In this connection it should be borne in mind that the dressing of wounds discharging pus in an open ward inevitably sheds the infecting organisms on to the bedclothes and so into the air and environment.

Howie (1956) suggests that bacteria should be attacked while they are still in the hospital environment and not only after they have invaded patients' tissues. We have already available a good deal of information about the sources and ways of spread of pathogenic bacteria in hospitals, but more investigation on this problem needs to be done. Much improvement could be obtained by making better use of the knowledge already available. Measures to control dust and carriers may be very thorough and barrier nursing performed to perfection, but so long as we allow dirty blankets to remain indefinitely on hospital beds and close our eyes to the fact that our woollen garments are heavily loaded with bacteria, we are failing to control the spread of potential pathogens.

Measures of control already in use are "barrier nursing" in selected cases, and covering the floors with a film of sticky polish to keep down dust, but it is evident from the results of the present investigation that these methods are not sufficient to keep the numbers of bacteria in the air below reasonably safe limits during normal ward activity.

The re-circulation of air over U.V. light in the large wards was not effective in reducing the numbers of bacteria carrying particles under ordinary conditions. In small rooms the reduction effected by the use of one machine did not bring the bacterial counts to levels safe for dressings, but the use of two machines under conditions of normal activity in a small room of 1,221 cubic feet capacity brought the bacteria count to 12.14 per cubic foot of air, which would make it more suitable for use as a surgical dressing-room than the wards are at present.

If the numbers of bacteria in the air are to be reduced significantly, measures which should be adopted as well as those mentioned above are first, the provision of clean blankets for each patient and the frequent washing of hospital blankets by a technique such as the "lissapol cirrasol" method. The possibility of the future use of terylene blankets should be borne in mind, as they might well prove less expensive in the long run than special laundering methods.

All members of staff who work in wards should wear clothing which can be frequently changed and easily laundered. The nursing profession has always been conscious of the necessity of wearing such clothing. Other members of staff have compromised by wearing a white cotton coat over ordinary woollen outdoor clothing, but medical students are allowed in the wards in the tweed coats and flannel trousers which they have worn daily for months. They should at least be required to wear a white coat or gown which covers them, for it would cut down the numbers of bacteria they scatter by fifty per cent. (Duguid and Wallace, 1948).

Where at all possible, vacuum cleaning should be adopted in all hospital departments, and indeed, when new hospitals are being designed, built-in suction should be included for this purpose.

If it were at all possible a special room should be equipped and kept for the sole purpose of doing surgical dressings and no wound should ever be uncovered in a general ward.

Operating Theatres.

When the results shown in tables 2 and 4 are considered together, it is apparent that the average numbers of bacteria carrying particles per cubic foot of air found are almost all much higher than the level suggested by Bourdillon and Colebrook (1946) as a reasonable standard for theatres where major operations are performed. In only three sampling sessions out of a total of twenty, was the average bacterial count per cubic foot of air below fifty, which is the standard suggested as reasonable for an ordinary occupied room. The counts found in each of the four theatres reflect the general conditions in them. Conditions in theatre A are the least satisfactory, and those in theatre B leave much to be desired. There are three other theatres similar to A in use in the hospital. The comparatively good result obtained in theatre C was probably mainly due to the quiet conditions prevailing during sampling, but the fact that it is a larger room, is less crowded with apparatus, has better arrangements for sterilisation and for preparation and induction of anæsthesia, may have contributed to this result. The counts obtained in theatre D are the only ones which conform to Bourdillon and Colebrook's standards for major surgery. In this theatre the ventilation rate (eleven changes per hour) is not greater than that found in the other theatres during summer, but this theatre is much larger than the others and is quite devoid of equipment apart from the operating table, the surgeon's table and the anæsthetist's trolley. The theatre is one of a suite, and all sterilisation and other preparations are done outside. All the staff, both medical and nursing, change from outdoor clothing into fresh theatre suits before scrubbing-up, and enter the theatre completely prepared for the operation. Movement is not great, is unimpeded, and is seen in table 2 and fig. 4, the counts during quiet periods are low.

As in the wards, any increase in activity in the theatres is associated with a rise in the numbers of bacteria in the air. This is illustrated both in tables 2 and 4, and in figs. 2, 3, 4 and 7.

Apart from the usual activity at the beginning and end of each operation, it was noted that the actions which caused a rise in the bacterial count were; movements of the operating table up and down, of the overhead lamps and of the anæsthetist; rinsing of the surgeon's hands in sterile lotion, mopping of the surgeon's forehead, opening of the doors of store cupboards, moving the curtain over the doorway, the passage of persons in the corridor outside, and the entry of visitors from time to time. The visitor may have prepared for his entry by donning a sterile mask, or a sterile mask plus a sterile gown, or a sterile mask, cap and gown, but this sterile clothing is put on over the wearer's ordinary clothes.

Duguid and Wallace (1948) have shown that this practice, which they describe as "surgical gowning," does not prevent the dissemination of bacteria from the clothing of the wearer, though it does effect a reduction of fifty per cent. when compared with the numbers shed into the air from a person wearing ordinary clothing and no gown. That surgical gowning is not effective has been confirmed during the present study by the observation made during an operating session, when a technician who was wearing sterile gown, mask and cap over his ordinary clothes, moved the gown and put his hand into his trouser pocket. This action was immediately followed by a rise in the bacterial count.

But during the present series of observations in operating theatres it has been noted that though the surgeon and one assistant will have changed into operating suits, quite often a second assistant and the anæsthetist will be content with "surgical gowning." Except for the staff working in theatre D, this was not an uncommon practice, and it must have contributed to the high level of bacteria generally found in the air of the operating theatres. One might also add that the sterile caps worn by the surgical and nursing staff to cover the hair often did not fulfil their purpose and masks were occasionally seen situated below the nose.

The operating theatres in the hospital were designed over fifty years ago almost at the beginning of the "surgical era," to cope with a volume of work which was very much less than that which exists at present. As they are now, they have to serve not only as operating theatres but as preparation room, sterilising room, scrubbing-up room, dressing room, and for the storage of equipment and other materials. When not being used as operating rooms they are often used as examination rooms for out-patients. In fact, the theatre fulfils the entire function of a modern operating suite, and according to modern standards they are not proper places even for the dressing of wounds.

In spite of the difficulties, something might be done to bring the bacterial counts down to safer levels, and it might be worth while to consider what is possible under the present circumstances. The following measures are suggested :—

The doors between the corridors and theatres should be kept shut; contaminated air from the corridors has been shown to enter the theatres during the present series of tests. Admission of any person to the theatre after an operation has begun should not be permitted except under exceptional circumstances. All of the staff, including the anæsthetist and the nurses, should change into fresh cotton clothes before actual preparation for the operation begins; this would perhaps not be possible under the present conditions, as accommodation for changing is very limited (and is only available to the surgical staff). If surgical suits are worn outside the theatre for an appreciable length of time, then they should be taken off and fresh suits put on before beginning another operating session.

Some thought should be given to redesigning masks, caps and gowns. After a mask is put on, it should never be handled and it should be so designed that it could not be pushed up and down under the chin each time the wearer feels uncomfortable. Many of the caps worn, even if put on so as to cover the head, after a time ride up and leave large areas of hair uncovered. If a surgeon is one of those people who is likely to sweat freely from the head or forehead, it would be advisable for him to apply a little vaseline to the roots of the hair and to the eyebrows.

Gowns are so cut that they often do not meet at the back of the neck and the top button has to be left undone so a space is left uncovered.

People should not come into the theatre in ordinary shoes and socks; cotton socks could be put on at the same time as surgical suits and special laundered over-boots which should be worn outside the theatre as little as possible.

The patient should be dressed in clean cotton garments with cotton operation stockings instead of wool which cannot be sterilised. Every patient, whether male or female, bald or hirsute, should have the head completely covered by a clean cotton cap. It might be a good thing if the patient's jacket had short sleeves so as to make for less disturbance of clothing when the anæsthetist is giving intravenous injections. Movement of every person in the theatre should be restricted to those essential and should not be sudden or vigorous.

Obviously "clean" cases should be dealt with first. The use of direct U.V. light after a "dirty" case for a certain period (about half an hour is suggested) in combination with the controlled ventilation will kill the bacteria in the air and on such surfaces as the rays fall upon.

The use of indirect U.V. light proved disappointing. Any reduction in numbers following its use was more than compensated for by the rise due to the general conditions which prevailed in the theatre. In other words, the amount of activity which existed kept the bacterial level too high for the U.V. light to have an appreciable killing effect.

SUMMARY.

A survey of the numbers of bacteria carrying particles in the air of the wards and operating theatres of a hospital ventilated by the Plenum system has been done.

The results obtained in the wards show that the ventilation rates, even in summer, are not sufficient to keep the bacterial levels below fifty during normal working conditions. When conditions are quiet during the day the levels are lower than

fifty, but they never reach a level which could be regarded as satisfactory for surgical dressings.

In the operating theatres the results of air sampling revealed the fact that the number of bacteria carrying particles in all except one, were maintained at a level which must be regarded as thoroughly unsatisfactory. *Staphylococcus pyogenes* (*aureus*) colonies were recovered from the air of one theatre during an operation for the amputation of a leg.

The value of indirect U.V. light in the theatres and wards was assessed. Under present conditions its use did not seem to produce effective results.

The re-circulation of air over U.V. light in a special prototype machine was of no advantage in the large wards under normal working conditions, even when the machine was running beside the slit sampler and a patient's bed. More bacteria were being added to the air than were being killed by the U.V. light.

Results obtained in the small clinical room were more encouraging. If the machine were able to deal with large enough quantities of air, then the balance between bacteria being added and bacteria being killed might be nearly equal.

The main factors in keeping the bacteria in the air at a high level are movements of bedclothes, clothing, curtains, persons and furniture.

Measures have been suggested which, in combination with those already in use, should bring down the numbers of bacteria in the air of the theatres to safer levels.

My thanks are due to Professor G. W. A. Dick for help and encouragement in the preparation of this paper; to the surgical, nursing and engineering staff of the Royal Victoria Hospital, Belfast, for their willing and helpful co-operation; and to Messrs. R. B. Stirling of Glasgow for the loan of the machine used for the re-circulation of air over U.V. light. The technical assistance was partly paid for by a grant to this department from the Medical Research Council, and this I wish to acknowledge.

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